# Evaluation of an Out-of-the-Window Air Traffic Control Tower Simulation for Controller Training

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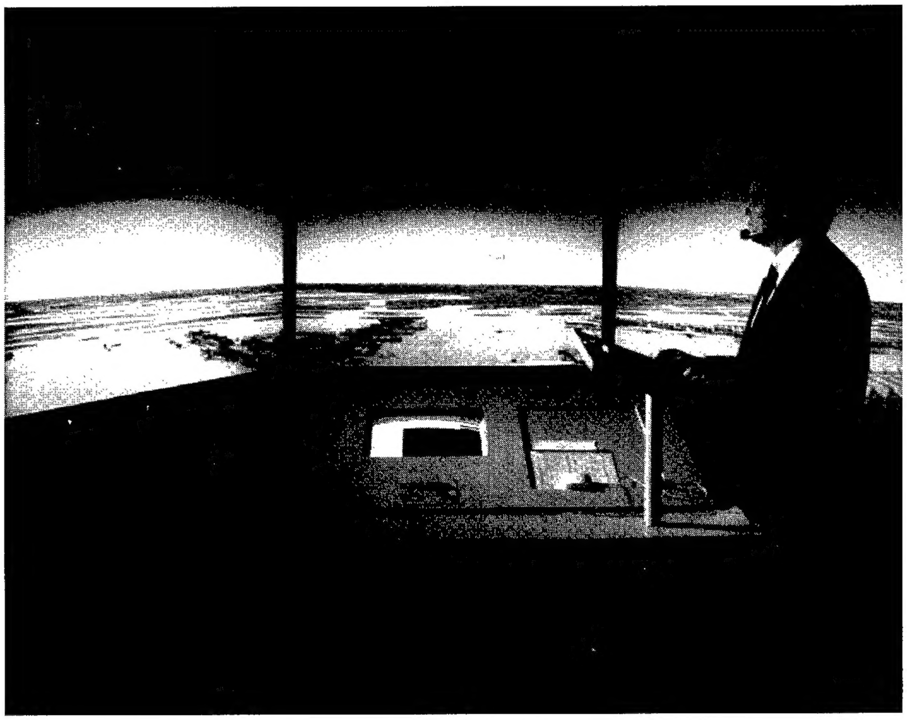



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13. ABSTRACT (Maximum 200 words)

This study gathered evidence concerning the potential usefulness of out-of-the-window air traffic control tower simulation for training tower controllers. Data were collected from all ten developmental controllers who completed simulation training at Chicago O'Hare International Airport during 1994. The simulation included one controller position, outbound ground control. An out-of-the-window view was projected on three visual displays which approximated the size of actual tower windows. Aircraft were representative of O'Hare, and appeared to move in three dimensions on the displays. The simulation could display the entire airport, but only 135 degrees could be seen at a time and no inbound aircraft were simulated. After five weeks of simulation training, the trainees became certified on outbound ground control in 25% fewer days than trainees who received the same amount of traditional training. However, the trainees using the simulation needed only slightly (5%) fewer total hours to become certified on this tower position. Evidence suggested that the simulation increased the trainees' working speed, enabling them to work under busier conditions, and hence more hours per day. Expert ratings of eight ground control skills based on actual tower observations were all higher following simulation training than following traditional training.

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# PREFACE

This investigation evaluated the effectiveness of an out-of-the-window tower simulation[1] by studying the first year of training conducted in the simulated tower. The author wishes to express gratitude to the ten student controllers whose training was studied in this evaluation. Their many observations provided an invaluable source of insight about the simulation.

Jon Bremseth, an O'Hare training specialist, operated the simulation. He previously developed a training laboratory using videotapes correlated to flight progress strips, setting the stage for the current, interactive simulation training facility. Jon served as the facility contact person for this evaluation. He also assisted this evaluation by ensuring that one session was videotaped for each trainee each week and by providing the corresponding flightstrips which were used in data reduction. He contributed useful observations on the productive use of out-of-the-window tower simulation, many of which appear in this report.

Many other individuals at O'Hare deserve recognition for their outstanding contributions to this evaluation. Ellen Jaeger is the Assistant Manager for Training at O'Hare. She and Roy Hillen, an O'Hare training specialist, collected preliminary data on trainee errors during their simulation training and provided information about the trainees' prior experience. Tower supervisors Bob Karnick and Tim Fitzgerald, and area manager Kevin Markwell provided ratings of trainee skills. Matt Dunne, Acting Assistant Manager of Traffic Management provided typical taxi delays, taxi times and aircraft rates during an outbound push. The author also recognizes and appreciates the critical support provided by Tower Air Traffic Manager, Bill Halleck.

The author thanks three individuals for their help with technical aspects of this project. Mitch Grossberg of FAA/ACT-500 contributed valuable suggestions on the format used to collect supervisor ratings. Patricia Pilanen, a tower training specialist at Logan Airport, answered many of the author's questions about tower training and drew the author's attention to the need for ground control trainees to learn to manage flight progress strips without reducing their attention to the airport movement areas. Karl Hergenrother of RSPA/Volpe Center created the data reduction programs used to reduce duration data from videotape, developed videotape data reduction procedures, and contributed valuable observations on the simulation process.

Objective data reduced from videotape played a key role in this evaluation. This exacting work was accomplished by Tufts University engineering psychology students, Ana Pons, Kathleen Kim, and Trudi Leone, while they were employed at RSPA/Volpe Center. Bill Voss at ATZ-200 provided the requirement for this study. Larry Cole at AAR-200 sponsored the effort. Their continuing interest and support were critical to the completion of this project.

1. Cover photograph of TowerPro™ courtesy of Wesson International, Inc.

# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

### LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

### AREA (APPROXIMATE)

1 square inch (sq in, in$^2$) = 6.5 square centimeters (cm$^2$)
1 square foot (sq ft, ft$^2$) = 0.09 square meter (m$^2$)
1 square yard (sq yd, yd$^2$) = 0.8 square meter (m$^2$)
1 square mile (sq mi, mi$^2$) = 2.6 square kilometers (km$^2$)
1 acre = 0.4 hectare (ha) = 4,000 square meters (m$^2$)

### MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

### VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft$^3$) = 0.03 cubic meter (m$^3$)
1 cubic yard (cu yd, yd$^3$) = 0.76 cubic meter (m$^3$)

### TEMPERATURE (EXACT)

°C=5/9(°F - 32)

## METRIC TO ENGLISH

### LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

### AREA (APPROXIMATE)

1 square centimeter (cm$^2$) = 0.16 square inch (sq in, in$^2$)
1 square meter (m$^2$) = 1.2 square yards (sq yd, yd$^2$)
1 square kilometer (km$^2$) = 0.4 square mile (sq mi, mi$^2$)
10,000 square meters (m$^2$) = 1 hectare (ha) = 2.5 acres

### MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

### VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m$^3$) = 36 cubic feet (cu ft, ft$^3$)
1 cubic meter (m$^3$) = 1.3 cubic yards (cu yd, yd$^3$)

### TEMPERATURE (EXACT)

°F=9/5(°C) + 32

## QUICK INCH-CENTIMETER LENGTH CONVERSION

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| INCHES | 0 | | | 1 | | 2 | | | 3 | | 4 | | | 5 |
| CENTIMETERS | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |

## QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °F | -40° | -22° | -4° | 14° | 32° | 50° | 68° | 86° | 104° | 122° | 140° | 158° | 176° | 194° | 212° |
| °C | -40° | -30° | -20° | -10° | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | 100° |

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

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## EXECUTIVE SUMMARY

The objective of this evaluation was to gather evidence bearing on the potential usefulness of out-of-the-window ATC tower simulation for training tower controllers. The FAA Research and Development Service (ARD) sponsored the development of an out-of-the-window simulation as a proof-of-concept demonstration. It was about to be used for the first time to train developmental controllers at O'Hare International Airport in Chicago. This simulation was a prototype (beta) version of TowerPro™ (Aviation Simulations, Inc.). It had been developed specifically to train outbound ground control at O'Hare. The data for this evaluation were collected on the progress and relative post-training proficiency of all ten developmental controllers who completed simulation training at O'Hare during 1994, the first year of its use.

The simulation implemented at O'Hare included one controller position, outbound ground control. An out-of-the-window view was projected onto three visual displays which approximated the size of actual tower windows. Computer-generated aircraft appeared to move in three dimensions on these displays at rates which varied with the type of aircraft. The aircraft were representative of the types and companies at O'Hare. A session included 30 to 90 aircraft in 50 minutes.

The simulation was limited to three screens, so that only a 135 degree section of the airport could be displayed at any one time. Controllers at O'Hare must observe aircraft movements on all sides of the tower. In the simulation, instead of turning to look through a different window, the trainees used a hand-held control to rotate or "pan" the displayed section to show the relevant part of the airport. The simulation was also limited to outbound aircraft: *No inbound aircraft were included in the simulation scenarios.*

The evaluation was constrained by the lack of a concurrent control group consisting of developmental controllers who would have received only traditional training. Instead, comparisons were made between the trainees who used the simulation and those who had previously been trained at O'Hare, prior to the installation of the simulation.

The primary measures of simulation effectiveness concerned how long (days and total hours) it took a developmental controller to become certified on the outbound ground control position. The primary measures were supplemented by ratings made by tower supervisors on specific ground control skills, following simulation training. These expert ratings were compared to the supervisors' and an area manager's *recollections* of the baseline strength of developmental controller skills after varying amounts of time.

Additional data were reduced from videotapes of the simulation training sessions. The measures obtained included taxi delay, defined as the time it took the ground controller to provide taxi instructions to an aircraft that was ready to taxi; taxi time, which began when an aircraft received taxi instructions and ended when it was instructed to switch radio frequencies to a tower frequency; and visual scanning directed toward the "window" or toward the stripboard. Instructor comments made during the videotaped sessions were classified according to topic and tallied to provide additional indications of the development of specific ground control skills.

Also, the first group of trainees' perceptions of the simulation training were solicited in a focus group session.

The data collected support the following conclusions:

**The out-of-the-window tower simulation used at O'Hare:**

- **is an effective tool for training many ground control skills and knowledge, and appears particularly effective in increasing trainees' working speed.**

- **is more effective for training outbound ground control than more traditional training techniques.**

The effectiveness of the simulation was indicated by the following:

**I. Trainees' ground control skills increased noticeably during simulation training.**

*Taxi delay decreased consistently from the second week to the end of training.*

*Stripboard scanning began to consistently decrease after the second week of training, while window scanning began to increase after the third week of training.*

*The amount of assistance needed for a trainee to properly handle a scenario decreased consistently throughout training.*

**II. Training using the simulator was more effective than traditional training.**

*The developmental controllers who were trained using simulation became certified on the outbound ground control position in 25% fewer <u>days</u> than developmental controllers who were trained without simulation. However, using simulation, the trainees needed about the same (only 5% fewer) <u>hours</u> to become certified on this tower position.*

*Expert ratings of eight ground control skills based on actual tower observations were all higher following simulation training than following traditional training.*

The difference between the days-to-certification and total hours-to-certification results can be explained in terms of working speed:

> ***The Working Speed Hypothesis: Simulation training increased developmental controllers' working speed, which enabled them to work in the actual tower under a wider range of conditions (i.e., under heavier or more complex traffic) and hence for more hours per day than with traditional training.***

**Recommendations**
Upgrading the simulation could be of value in providing training for the following:

1. Inbound ground control and coordination between inbound and outbound ground control positions
2. Reflexive, correct communications
3. Scanning and situational awareness
4. Understanding what a pilot can see from the cockpit
5. Smooth transition between window scan and BRITE/ASDE displays
6. Teamwork

Simulation training at O'Hare requires use of the simulation facility for roughly six months per year. The most productive use of tower simulation at O'Hare would incorporate enhanced capabilities and new areas of application that would permit more extensive use. The following enhancements and new application areas are discussed:

1. Individual performance enhancement for current controllers
2. Team performance enhancement for current controllers
3. Training in the handling of unusual situations
4. Optimizing training through the application of experimental training conditions
5. Tower controller candidate screening
6. Assessment of new tower equipment, procedures, and airport configurations.

# 1. INTRODUCTION

## 1.1 PURPOSE

The purpose of this effort was to provide human factors testing and evaluation of an air traffic control tower (ATCT) out-of-the-window (OTW) controller training simulation located at O'Hare International Airport in Chicago. It was intended to analyze and quantitatively measure, to the extent possible, the potential usefulness of devices of this type if they were to be installed at selected high density or complex ATC facilities. Goals included:

- An evaluation of the impact of tower simulation on time-to-certification on position
- Quantitative estimates of any savings to the user (airlines, aircraft operators)
- Recommendations for the most productive application of OTW simulators
- Recommendations for functional specifications of future simulators based on current systems
- Evaluation of the potential of tower simulation for rapid prototyping to assess the impact of new tower equipment, procedures, or configurations.

## 1.2 BACKGROUND

The U.S. air traffic system requires well-trained tower controllers. Controllers receive training at the FAA Academy, but the training for high activity (operational level 5) towers normally follows years of operational experience as a full performance level controller at less active towers, plus many months of training at the high activity tower. Until certified on all tower positions, trainees are termed "developmental controllers." Developmental controllers do not work independently at a tower position until they have met the criteria for certification on that position. At the nations' high activity towers, the tower positions typically include flight data, clearance delivery, ground control, local control, and supervisor.

This report concerns outbound ground control training at O'Hare Tower. At O'Hare, controllers handle the largest number of aircraft operations of any tower in the country. In 1992, O'Hare recorded nearly thirty million enplanements, with a seventy to eighty percent increase in enplanements expected by 2010[2]. The volume and complexity of its traffic make outbound ground control at O'Hare arguably the most challenging position to work at and the most difficult position to learn of any position at any air traffic facility in the U.S.

During daily periods of high activity, ground control responsibilities are divided between two positions at O'Hare: the inbound ground control position is responsible for arrivals taxiing in to their gates; outbound ground control handles departures taxiing out toward a runway. Weather accounts for much more delay than any other cause, but according to the FAA Aviation Capacity Enhancement Plan, taxi-out consistently accounts for more delay than the other phases of flight[3]. This statistic suggests the importance of providing safe and efficient air traffic services to outbound aircraft. The same source indicates that O'Hare ranked second in delays of the 55 airports at which the FAA collects air traffic delay statistics.

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2. FAA. (Sept. 1994). Terminal Area Forecasts FY 1993-2010. FAA-APO-94-11.
3. FAA. (1994). Aviation Capacity Enhancement Plan. DOT/FAA/ASC-94-1.

The outbound ground control position at O'Hare requires considerable knowledge and skill. The outbound ground controller must first decide which aircraft to call, whether to provide taxi instructions or to make a traffic call. Determining the priority of duty requires almost continuous attention to the situation on the taxiways, particularly during an "outbound push" (i.e., when relatively many aircraft are departing). At the same time, he or she must maintain an awareness of the location of aircraft that are ready to taxi. This controller decides which one of O'Hare's eight departure runways to send each departing aircraft to, and in what sequence, decisions that must take into account the type of aircraft and its initial route of flight. Then the outbound ground controller must decide which series of taxiways the aircraft should use to reach its runway. After transmitting the departure runway and taxi route to the pilot, ground control must make certain that the pilot understood the instructions, and follows the taxi route. Often the outbound ground controller needs to coordinate with the inbound ground controller and local controllers when the aircraft is expected to enter their areas of responsibility.

The outbound ground controller has typically required more than a year of traditional on-the-job training (OJT) before a supervisor certifies his or her ability to work independently at this position. During this time, an instructor must supervise the developmental controller (trainee) while the trainee controls aircraft. At times, the situation on the airport surface is too busy for the trainee to handle, requiring the instructor to take over. At other times, there is too little traffic or complexity for the trainee to increase the level of his or her skills. The ideal training situation is one with enough traffic and complexity to allow the trainee to gain confidence in handling difficult situations, but also one that is not so difficult that safety or the expeditious flow of aircraft could be reduced. The ideal training situation does not occur often in actuality, so OJT proceeds more slowly than if the ideal training situation were always available.

In an effort to improve the speed and quality of training, the training specialists at O'Hare were provided a prototype tower controller training simulator, TowerPro™ (Aviation Simulations, Inc.). This prototype was developed for a proof-of-concept demonstration of its potential for training outbound ground control at O'Hare. The simulation operator, who was also a training specialist, prepared simulation scenarios for training on what he believed would provide the ideal amount of traffic and complexity for each trainee. Simulation thus permitted the training of ground controllers to always proceed under planned conditions. To the extent that this training was sufficiently realistic to transfer to performance in the tower, simulation training was expected to reduce training time, particularly for the outbound ground control position.

## 1.3 CONSTRAINTS ON THE EVALUATION

This evaluation was conducted as a field study. As such, it was limited in the use of statistical control groups and independent variables. This section describes these constraints and their impact on the evaluation.

- Lack of a concurrent control group
- Ongoing training
- Sample size

#### 1.3.1 Lack of a Concurrent Control Group

A constraint on the evaluation was the lack of a concurrent control group consisting of developmental controllers who would have received only traditional training. No concurrent control group was included in the investigation because it was not considered ethical to withhold what was expected to be better training from a control group. A possible alternative involved comparisons of simulation training at O'Hare to traditional training at another tower. However, the results of such comparisons would be suspect due to confounding with other differences between the two towers. Instead, comparisons were made between the trainees who used the simulation and those who had previously been trained at O'Hare, prior to the installation of the simulation.

#### 1.3.2 Ongoing Training

The data gathered for this study were collected during the first year the training staff at O'Hare used an OTW tower simulator to train tower controllers. Three groups of controllers received training over the course of this one-year study. The O'Hare training staff gave considerable thought to the way they used the simulator and modified their training practices in an attempt to improve the training of each successive group. As a result, the training methods used for the three groups differed. This led to instances where it appeared inadvisable to combine the training data obtained from the different groups.

Another constraint on the evaluation resulted from the increasingly difficult demands of the training program. Simply stated, more skills were required at the end of training than at the start (see section 3.2). Due to this increasing demand, the trainees needed to increase their skills for their performance to remain at the same level. This constraint complicated the interpretation of data obtained from simulation training sessions.

#### 1.3.3 Sample Size

This evaluation was based on the performance of all ten developmental controllers who received simulation training during 1994 at O'Hare Tower. The small size of this sample precluded conducting statistical tests on many of the differences observed.

## 2. THE SIMULATION

### 2.1 DESCRIPTION

The training simulation evaluated was TOWER/Pro™, a product of Aviation Simulations, Inc. It cost approximately $500,000. It was set up in an O'Hare Tower training room as shown in Figure 1. There, it was used to train performance on the outbound ground control position. The three visual displays showed aircraft moving about the simulated O'Hare Airport. The displays were approximately the size of actual O'Hare Tower cab windows, although they were partitioned somewhat differently. Because it presented the airport in a manner virtually identical to the airport as seen through the actual tower windows (but see the field of view limitation described in section 2.2.1), the device is considered an "out-of-the-window" tower simulator. The simulation showed the entire airport including all taxiways and runways, permitting practice with all runway configurations. The computer-generated aircraft appeared to move in three dimensions at rates which depended upon the type of aircraft. Aircraft crossed from display to display without interruption, much as planes seen from the tower cab appear to move along taxiways from window to window. The simulation included a representative mix of air carriers and propeller-driven types of aircraft. The airport was displayed as if seen from slightly above the tower cab because the simulation's airport image was constructed from photographs taken from the roof of the cab.

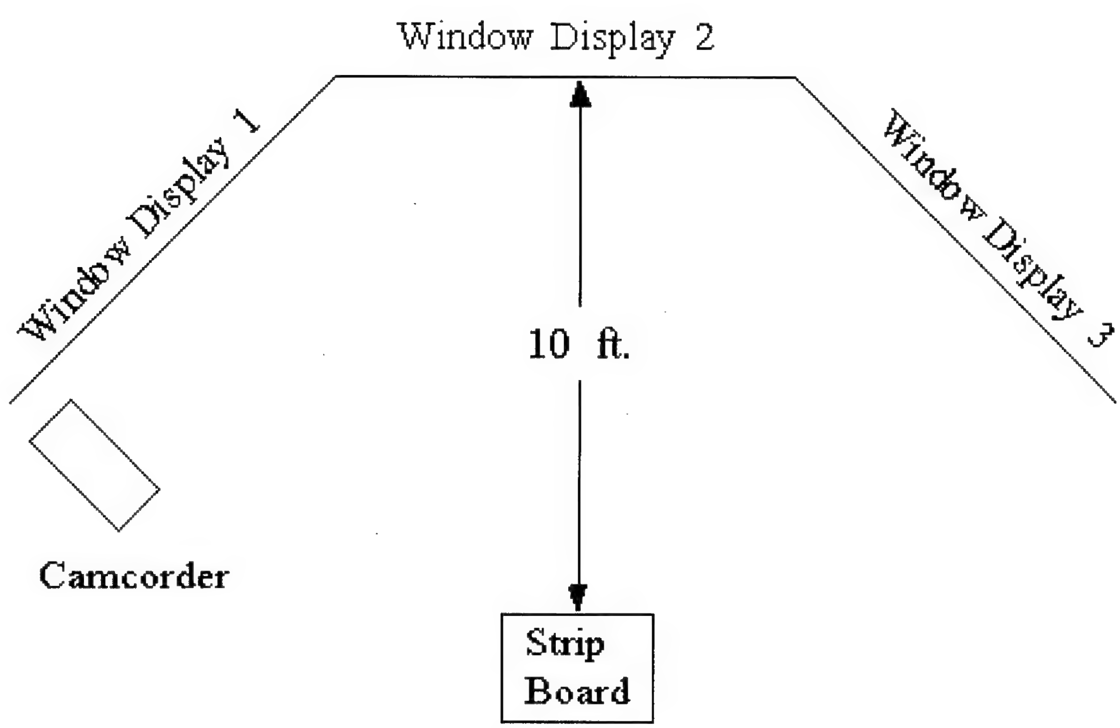


**FIGURE 1. SIMULATION EQUIPMENT LAYOUT**

The airport and aircraft images were projected from a ceiling-mounted source that was separated by a curtain from the rest of the training room. The ambient lighting in the training room was maintained at a dim level while the simulation was running to minimize reductions in color contrast on the window displays. Accurate color representation is important because the colored logos and markings on aircraft provide cues to an aircarrier's company, and controllers use them to identify aircraft.

An instructor and the simulation operator provided training in the simulated O'Hare environment. Each instructor was assigned to a pair of developmental controllers, and instructed them during simulation training and during OJT. While one trainee assumed the role of outbound ground controller, the other served as a "ground meterer." The ground meterer's role in the simulation was to set up the flight strip for each flight as it was about to enter the simulation.

During the simulation, the trainee stood behind a flight progress strip bay facing the three screens. He (all trainees during the one-year data collection period were male) wore a standard headset for communication with simulation "pilots." A camcorder used to collect data for this study was located on the trainee's left and was focused on the trainee to record his voice and the direction of his gaze. The ground meterer stood to the trainee's left near a computer display which showed the airport, current aircraft positions, and the simulation clock. The instructor stood to the right and behind the trainee. The simulation operator, who was also a training specialist, sat behind the instructor at a console with aircraft movement controls and a display showing the airport and aircraft locations. The trainee could see neither the ground meterer's nor the simulation operator's display.

## 2.2 LIMITATIONS OF THE SIMULATION

Every simulation embodies limitations. Following are the limitations of the simulation upon which this report is based:

- partial field of view
- automated controller speech recognition/synthetic pilot speech
- no inbound aircraft.

### 2.2.1 Partial Field of View

O'Hare Tower overlooks the airport on all sides, permitting controllers to view all of the taxiways and runways, which are found on all sides of the tower. Since the ground and local controllers must visually locate each aircraft before providing it with movement instructions and clearances, their scanning must include every direction. The simulation could display all of the airport, but only 135 degrees of arc was visible at a time through the three window displays. At O'Hare, the ground controllers often move about the tower cab for a better view of the airport. In the simulation, though, the trainees had to select one 135 degree segment to view at a time (Figure 2). They used a handheld control similar to a computer mouse to rotate or "pan" the view until the desired segment of the airport could be seen. Trainees could vary the panning rate from approximately 45 degrees per second to 150 degrees per second. Panning from a fixed

position thus took the place of moving around the tower. Thus, trainees needed to learn an artificial simulator skill (panning) to participate in simulation training.

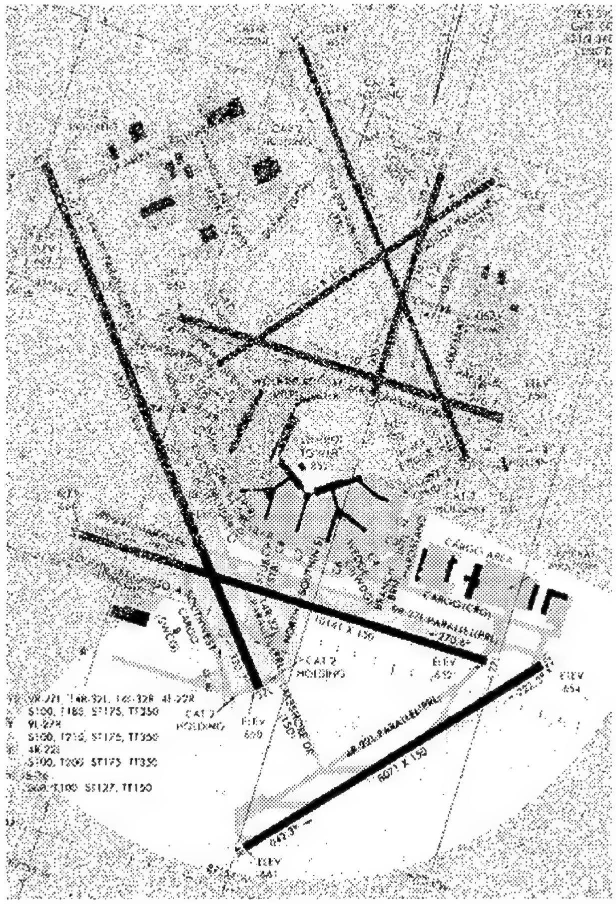

**FIGURE 2. PARTIAL FIELD OF VIEW**

It was probably more difficult for the trainees to locate, identify, and track aircraft in the simulation than in the real tower because they needed to pan the displayed 135 degree segment of the airport to the part that they wanted to see. Some evidence of this difficulty appeared in a focus group conducted with the first group of trainees (see Appendix A for a summary). When a controller scans the airport from the real tower, he or she physically changes his or her view with eye movements, head turns, and body movement. The perceptual system adjusts to produce a stable view, a phenomenon known as position constancy[4]. In the simulation, when the trainees panned the view to bring a target onto the display, display motion was not accompanied by self-motion, so relatively fast panning produced an unstable view. The effect of panning was that the trainees could not identify aircraft while panning quickly, but instead needed to either pan slowly or wait until the display stopped.

**4**. Matlin, M.W. (1988). Sensation and Perception (2nd Ed.). Allyn and Bacon.

2.2.2 No Inbound Aircraft

Inbound aircraft were not simulated. Training focused on the outbound ground control position and thus required a maximum of practice handling outbound aircraft. Limiting the simulation to inbound aircraft also maintained the complexity of the traffic at levels appropriate for new developmental controllers.

2.2.3 Automated Controller Speech Recognition/Synthetic Pilot Speech

The simulation included automated speech recognition and synthetic speech capabilities. Speech recognition was intended to accept correctly phrased taxi instructions and then respond automatically with the corresponding aircraft movements and an automated pilot readback using synthetic speech. The automated system was available, but its use was discontinued because it hindered training by placing several artificial constraints on trainee speech. As a result, speech recognition was discontinued during the third week of attempted use by the first group of trainees (see Appendix A for trainee observations regarding speech recognition). The following constraints were observed:

1. Trainees needed to remember to pause at the end of each instruction, and to not pause in the middle of the instruction. This often interfered with a controller's speech cadence.

2. It was impractical to train the speech recognition system to recognize the complete lexicon used by ground controllers to assist pilots. If the automated system failed to understand an instruction, the utterance did not elicit a simulator response. As an example, it did not recognize both grouped and ungrouped numbers in aircraft callsigns. Also, unlike real pilots, the simulation did not recognize common taxi instructions which identified the relative position of aircraft, such as "Join alfa behind the second MD80 on your left." When a recognition failure occurred, the trainee needed to rephrase and re-issue the instruction, which slowed and disrupted performance.

3. The speech recognition system artificially limited the ways a trainee could issue instructions to multiple aircraft because each aircraft needed to respond before another could accept an instruction. This limitation interfered with training on the effective use of the ground control frequency.

4. Trainees needed to "train" the speech recognition system to recognize their voices, requiring several days that were then not available for training.

5. Synthetic pilot responses (readbacks and aircraft movements) occurred more slowly than in actual operations.

## 2.3 PRECURSOR TO SIMULATION TRAINING AT O'HARE

In 1989, the O'Hare training staff began to use a large screen television to display a videotape of the airport taken with an 8 mm camera. Flight progress strips were correlated to the videotape. This non-interactive training aid was used successfully to train developmental controllers to issue taxi instructions, sequence flight progress strips, and make traffic calls. This precursor of simulation training was not interactive. The training specialist could pause the videotape to ask what the trainee would do next or how he or she would handle a particular situation, but the trainee could not alter the flow of traffic. Each group that was trained using this laboratory aid completed a post-training evaluation. Many respondents found the video "lab" to be very helpful.

## 3. OUT-OF-THE-WINDOW SIMULATION TRAINING METHODS

### 3.1 TRAINEES AND SCHEDULE

Ten developmental controllers completed simulation training at O'Hare during the one-year data collection period. Seven of them later became certified on outbound ground control. They participated in three groups. The first two groups each consisted of four trainees, and the third group initially consisted of three, one of whom was required to interrupt simulation training for medical reasons. He completed simulation training after the data collection period had ended. Of the seven who became certified on outbound ground control, three were in Group 1, three were in Group 2, and one was in Group 3.

Each trainee participated in the simulation as the outbound ground controller for one hour daily, four days per week. The trainees worked in pairs. One pair participated for two hours in the morning, and the other pair participated in the afternoon. While one pair was in simulation training the other received OJT in the tower. At first OJT consisted of work at the clearance delivery and flight data positions. As the trainees' skills advanced, they began OJT at the ground and local control positions.

### 3.2 SIMULATION TRAINING PROCEDURE

Prior to each session, the simulation operator prepared an aircraft schedule including the type and company of each outbound plane and the time and gate where it would enter the simulation. The aircraft were one of two components in each simulation scenario. The second component was the Plan, which corresponded to an airport configuration. The Plan indicated the active runways that the trainee was to assign to the aircraft, depending upon their type, company, and gate. At the start of a session, the simulation operator announced the Plan that was to be applied. See Table 1 for a list of the Plans in use at O'Hare during the year data were collected.

**TABLE 1. AIRPORT CONFIGURATIONS AND DEPARTURE RUNWAYS AT O'HARE AIRPORT**

| Plan (Configuration) | Departure Runways |
|---|---|
| Weird | 32L at T10, 22L |
| X | 32L at T10, 4L, 9L, some 32R, 14L, 32L full length |
| B | 22L, 27L |
| 14's | 9L, 9R, 27L |
| 27's | 32L at T10, 32R |
| 9's | 4L, 9R |
| Modified X | 4L, 9R, 32R |
| 14R/9R | 9L, 22L, some 14L |

Also prior to each session, a paper flight strip was printed for each aircraft showing its callsign, initial route of flight, gate, and the time it was scheduled to appear at its gate. The flight strips, in standard plastic holders, were arrayed on the ground meterer's table in the order that the aircraft were scheduled to enter the simulation. After the session began, the ground meterer monitored the simulation time on his display. When an aircraft was scheduled to enter the simulation, he set its flight strip in the trainee's (controller's) strip bay.

An aircraft was ready to taxi in response to the simulation operator's movement commands after it automatically pushed back from its gate and moved toward the taxiways. The controller trainee called aircraft and issued taxi instructions through the headset push-to-talk microphone while marking and moving the plane's flight strip. The simulation operator then responded as the pilot of the aircraft, reading back instructions and taxiing the aircraft. The trainee continued to issue verbal instructions guiding each aircraft along the taxiways until he instructed the pilot to switch radio frequencies to a tower frequency. As the trainee worked the simulated outbound traffic, the instructor and simulation operator responded to his decisions with suggestions, questions, and comments. The sessions lasted approximately 50 minutes and were followed by a brief review.

In the simulation, the simulation operator (a training specialist) and instructor asked questions, made suggestions, and commented on the trainee's decisions. The simulation operator also responded as a pilot (actually, as all of the pilots). In the pilot role, he provided verbal readbacks and acknowledgments, taxied the aircraft and, following the handoff to a tower frequency, taxied the aircraft to the assigned runway and made it depart. The simulation operator paused the simulation when extended discussion appeared necessary. The simulation was paused infrequently (once or twice in a typical session); pauses lasted less than two minutes.

As the trainees' proficiency increased, they were expected to demonstrate more ground control skills and to handle more aircraft. Session objectives became more complex with the progressive addition of more advanced skills, as shown in Table 2. The rate at which aircraft appeared in the scenarios was gradually increased from one aircraft every two minutes (30 total) to one every forty-five seconds (80 total). The airport configuration or Plan was changed daily, but Plan Weird and Plan B were used more often in training because they were more frequently encountered in actual operations. A change of configuration (e.g., Plan 27's to Plan Weird) was practiced during the last week of training.

**TABLE 2. TRAINING OBJECTIVES**

| Phase of Training | Objectives |
|---|---|
| Early | Issue correct taxi routes, master stripboard management |
| Middle | Assign appropriate runway, issue correct taxi instructions, master stripboard management |
| Late | Assign appropriate runway, issue correct taxi instructions, master stripboard management, make traffic calls, handle configuration changes |

## 3.3 MODIFICATION OF TRAINING METHODS

As stated earlier, this study was based on data gathered during the first year the training staff at O'Hare used an OTW tower simulator to conduct training. They modified some training techniques over the course of the year. For example, whereas the first two of the three groups of trainees obtained practice on all O'Hare air carriers throughout their training, the training methods used for the third group emphasized one half of the airport at a time by first concentrating on the American Airlines rush. One anticipated benefit of this training strategy was that it would reduce the amount of panning required and thus reduce any distration panning might have created.

A set amount of training was planned for the first two groups. In contrast, the third group was given training until a criterion was reached. As a result, one Group 3 developmental controller received four weeks of simulation training, while the other received this training for three weeks. The criterion consisted of a demonstration that the trainee could:

- issue correct taxi routes
- effectively manage the stripboard
- assign the appropriate runway
- issue correct taxi instructions
- make traffic calls when needed.

The simulation's automated speech recognition/pilot response system was used only during the first three weeks of the first group's four-week simulation training (see section 2.2.3). The second and third groups received simulation training without automated speech recognition/synthetic speech. Group 2 received one week more simulation training than Group 1 because it was not necessary to take away the time needed to "train" the automated speech recognition system from simulation training.

# 4. EVALUATION METHOD

## 4.1 MEASURES OF EFFECTIVENESS

This report describes an evaluation of the first year of training using an OTW simulator to teach the skills required to perform outbound ground control at O'Hare Tower. Since an important goal of using the tower simulation in training was to reduce training time, **the primary evidence used to evaluate its effectiveness was the time required for the simulation-trained controllers to become certified on outbound ground control, compared to facility records.** To augment these data, the perceptions of tower supervisors were used to compare simulation-trained to traditionally trained developmental controllers on a variety of ground control skills. Their ratings helped to identify the specific ground control skills that simulation training benefited and the strength of these skills following simulation training.

The evaluation was also based on objective evidence reduced from videotapes of the simulation training sessions. Three types of evidence were reduced from the videotapes:

- Taxi Delay: how long the pilot waited before receiving taxi instructions
- Taxi Time: how long aircraft were under the control of the ground controller
- Scan: the proportion of time a trainee's gaze was directed toward the window displays or toward the flight progress strip bay.

Instructor comments found on the videotapes were quantitatively analyzed to provide additional indications of the development of specific ground control skills and to gain a better understanding of the simulation training process.

## 4.2 VIDEOTAPED TRAINING SESSIONS

Taxi time, taxi delay, scanning, and instructor comment data were reduced from videotapes of training sessions. One training session for each developmental controller was videotaped each week for later analysis. The videotaped sessions were conducted as normal simulation training sessions. Some exceptions were made for the purposes of the analysis: The same Plan (Plan X) was used in the videotaped sessions during the first and last weeks of simulation training for Group 1. The same Plan (Plan Weird) and the same aircraft rate (1.5 per minute) was used in all of the second group's videotaped sessions.

The training staff increased the aircraft rate for Group 1 each week during the four week simulation training period. The rate increased from .5 aircraft per minute during the first week to 2 aircraft per minute during the last week. The videotaped problems for Group 2 all included 90 aircraft and used "Plan Weird," one of the two most common configurations of the eight configurations used at O'Hare (the other is Plan X). The roughly 90 aircraft per hour rate approximates the departing aircraft rate in an actual outbound push. These parameters were kept constant in the recorded sessions for the purpose of this investigation. Training specialists determined the parameters used in the regular training sessions, depending upon the trainee's skill level and particular training needs.

# 5. RESULTS AND DISCUSSION

## 5.1 POST-SIMULATION TRAINING MEASURES

### 5.1.1 Days-to-Certification

The time (i.e., the number of days and total hours) it took developmental controllers to become certified to work independently at the outbound ground control position was the primary measure used in this study. Days-to-certification was measured from the date a developmental controller began working full time in the tower, having completed simulator training, to the date a tower supervisor certified him or her on outbound ground control. The hypothesis was that the simulation-trained developmental controllers would take fewer days than non-simulation-trained developmental controllers to become certified. The test of this hypothesis involved a comparison between simulation-trained controllers and non-simulation-trained controllers on days-to-certification on outbound ground control. The non-simulation or "traditionally trained" group had received four weeks of training in the videotape lab described in section 2.3. Their days-to-certification was also measured from the date they began working full time in the tower.

Only data from those non-simulation-trained controllers who began training after January 1, 1993 were included in the no-simulation group. Prior to January, 1993, O'Hare certified controllers on the outbound and inbound ground control positions together. Since simulator training was only given on outbound ground control, the days taken for certification on that position alone were the most relevant. Thus, the seven controllers who started training in or after January, 1993, were compared on days-to-certification to the seven controllers who became certified on outbound ground control following simulator training[5]. This comparison is illustrated in Table 3.

**TABLE 3. DAYS-TO-CERTIFICATION**

| | Days-to-Certification | | |
|---|---|---|---|
| | N | Mean | Standard Deviation |
| Simulation | 7 | 148.57 | 49.65 |
| No Simulation | 7 | 198.71 | 52.52 |

Table 3 shows that the simulation-trained developmental controllers took 50.1 days less, a 25.2 % reduction in the number of days-to-certification on outbound ground control. The difference is statistically significant, $t\,(12) = 1.84$ ($p < .05$), in a one-tailed test. This finding supports the hypothesis that developmental controllers who received simulation-training take fewer days to become certified on the outbound ground control position than non-simulator trained developmental controllers.

5. Three developmental controllers were certified on outbound ground control following the year in which the data were collected. Including this data would have produced a mean of 162.6 days and a standard deviation of 49.85 days.

### 5.1.2 Hours-to-Certification

The second part of time-to-certification is the total number of hours required. The hypothesis was that the developmental controllers who received simulation-training would take fewer hours to become certified than non-simulator trained developmental controllers. The test of this hypothesis involved a comparison between the same two groups of developmental controllers that were compared in section 5.1.1.

Table 4 gives the number of hours simulation-trained developmental controllers required for certification on outbound ground control and the hours-to-certification required by trainees without simulator training. They are approximately equal (a Mann-Whitney test[6] failed to reveal a significant difference, $p > .05$). Therefore, simulation training was effective in increasing trainees' skills to a point where the trainees could acquire the needed amount of OJT in fewer days, but it did not appear to reduce the total amount of OJT needed.

**TABLE 4. HOURS-TO-CERTIFICATION**

| | Hours-to-Certification | | |
|---|---|---|---|
| | N | Mean | Standard Deviation |
| Simulation | 7 | 84.93 | 21.18 |
| No Simulation | 7 | 89.42 | 12.53 |

It will be recalled from section 1.2 that when the density of traffic requires a faster working speed than a developmental controller can produce, the instructor must take over the position. The developmental controller then loses an opportunity to increase his or her ground control skills through practice. Accordingly, a hypothesis that would explain the time-to-certification results is that simulation training enables trainees to work more rapidly and thus to handle higher traffic densities in OJT. This can be called the *working speed hypothesis*.

The working speed hypothesis suggests that with simulation training, developmental controllers can obtain more hours of OJT per day, resulting in a need for fewer days of OJT than without simulation training. That simulation training did not appear to affect hours-to-certification suggests that simulation training does not address at least some critical ground control skills. These skills apparently develop independent of working speed so that an increased working speed does not reduce the number of hours of OJT needed to develop these other skills. The post-simulation-training supervisor ratings presented in the following section (5.1.3) and the training session measures presented in section 5.2.5 provide evidence related to the identification of these skills.

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6. This nonparametric test was used because the homogeneity of variance assumption underlying the more powerful parametric t-test was not met, as indicated by the standard deviation data presented in Table 4.

### 5.1.3 Tower Supervisor and Area Manager Ratings of Ground Control Skills

The measures of time-to-certification provide overall indices of the benefits that can result from simulation training, but these measures do not indicate the effect of simulation training on specific skills. Supervisory (expert) rating data were obtained to permit an examination of the skills exhibited during initial outbound ground control performance following simulation training. The strengths of these skills were compared to a baseline that represents the development of ground control skills without simulation training.

The baseline was constructed from ratings of typical OJT progress for traditionally trained average and fast learners on eight categories of ground control skill. An O'Hare Tower area manager and two O'Hare Tower supervisors made the baseline ratings. Each of the raters had worked as O'Hare instructors, area manager, or supervisors for at least six years. Thus, all had evaluated ground control skills at O'Hare prior to the use of simulation training.

The baseline was constructed from the supervisors' and area manager's *recollections.* This procedure was chosen because it was not possible to obtain the baseline ratings from direct observation. For each skill category, the supervisors estimated the strength of the skill for a developmental controller with one week to 12 months experience in the tower. They used five-point scales to make their ratings in each of the eight skill areas. The mean baseline ratings for "average learners" and "fast learners" and the meaning of each point on each of the 5-point scales appear in Appendix B .

The supervisors were asked to provide ratings on the same eight skills for the simulation-trained developmental controllers following each group's completion of simulation training. The ratings for a trainee were to be made as soon as possible following sufficient observation of his work in the tower. In all cases they were completed within three weeks following the end of simulation training for the individual, after the supervisor had observed the trainee's ground control skills for at least one hour. The ratings for Group 1 were made two weeks after the supervisors and area manager provided the baseline data.

Table 5 presents the rated strengths of the eight skill categories following one month of simulation training compared to the strengths of the same skills following one month of traditional training. The table presents the mean ratings for the seven developmental controllers who became certified on outbound ground control. Table 6 shows how many months of OJT it would take average or fast learners to reach the same level of skill that the simulation-trained controllers attained within three weeks following simulation training. Both baseline and simulation groups received approximately one month of training prior to OJT.

## TABLE 5. STRENGTH OF GROUND CONTROL SKILLS FOLLOWING ONE MONTH OF SIMULATION TRAINING COMPARED TO BASELINE

| | **Simulation** | **Baseline (No Simulation)** | |
|---|---|---|---|
| **Skill** | **Strength (1-5)** | **Average Learner: Strength (1-5)** | **Fast Learner: Strength (1-5)** |
| Visually scans airport surface | 3.21 | 2.0 | 2.7 |
| Maintains efficient traffic flow | 3.21 | 2.0 | 1.7 |
| Maintains aircraft identity | 3.71 | 2.0 | 2.7 |
| Working speed | 3.71 | 1.3 | 2.7 |
| Effectively manages stripboard | 2.89 | 1.7 | 2.0 |
| Missed/delayed traffic calls | 3.0 | 1.0 | 1.7 |
| Communication is clear and concise | 3.36 | 1.7 | 3.0 |
| Makes unnecessary transmissions | 2.93 | 1.0 | 2.0 |
| Overall | 3.25 | 1.59 | 2.31 |

Table 6 shows that according to the area manager and tower supervisors whose impressions were obtained, the skills of developmental controllers who received simulation training were advanced compared to the skills of those who received traditional training. Early in OJT, simulation-trained developmental controllers demonstrated ground control skills considered equivalent to traditionally trained average learners following five months of OJT.

Simulation training was particularly effective in training *working speed*, where the mean rating of 3.71 indicated that the trainee could work at a speed that was more than adequate for moderate workload (3.0) and close to adequate for high workload (4.0). This finding is consistent with the **working speed hypothesis** proposed in the preceding section. This explanation suggested that simulation training increased working speed, enabled the trainee to handle higher traffic densities, and hence permitted the trainee to work traffic more hours per day.

**TABLE 6. EQUIVALENT MONTHS OF OJT: SIMULATION TRAINING COMPARED TO BASELINE**

| Skill | Simulation<br>Months of OJT | Baseline (No Simulation)<br>Average Learner: Months of OJT | Fast Learner: Months of OJT |
|---|---|---|---|
| Visually scans airport surface | <1 | 4.42 | 1.51 |
| Maintains efficient traffic flow | <1 | 5.02 | 3.7 |
| Maintains aircraft identity | <1 | 5.42 | 2.07 |
| Working speed | <1 | 6.67 | 4.02 |
| Effectively manages stripboard | <1 | 4.63 | 2.38 |
| Missed/delayed traffic calls | <1 | 5.0 | 3.0 |
| Communication is clear and concise | <1 | 4.17 | 2.17 |
| Makes unnecessary transmissions | <1 | 4.9 | 2.46 |
| Overall | <1 | 5.03 | 2.66 |

## 5.2 SIMULATION TRAINING MEASURES

Each developmental controller was videotaped once each week during simulation training. The following objective data were then reduced from the videotapes: taxi delay, taxi time, and the percentages of time a trainee's scan was directed toward the "windows" or toward the simulation stripboard.

Taxi delay and taxi time provide measures of general planning ability and efficiency. Training was expected to result in reduced taxi delay and taxi time. Stripboard scan time is a measure of the attention required to stay organized by marking and moving flight strips. Controllers are trained to minimize stripboard scanning because it takes time from scanning the situation on the airport movement areas. Thus training was expected to increase window scanning and to decrease stripboard scanning.

### 5.2.1 Preliminary Data Considerations and Analysis

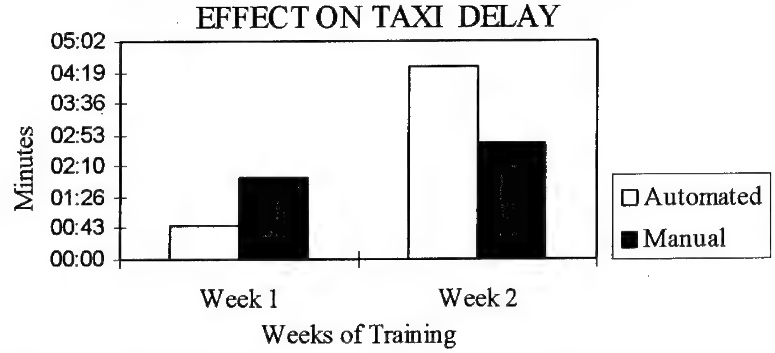
The Group 3 training data were excluded from analysis for several reasons. In Group 3, only two developmental controllers of the three who began simulation training completed it: one needed to postpone further training for medical reasons after three weeks. The use of training-to-a-criterion instead of a previously set number of weeks of training (see section 3.2) resulted in different amounts of training given to the remaining two trainees who completed simulation

training. In view of these and other differences between Group 3 and the other two groups, it appeared inappropriate to combine the three groups' training data. Group 3 provided insufficient data (a total of eight sessions for three trainees) to conduct a meaningful separate analysis of Group 3 alone.

The Group 1 data required preliminary analysis to assess any impact of the automated speech recognition/synthetic speech system on the measures of training. The automated system was used during the first two to three weeks of Group 1 training (see section 2.2.3). It appeared to lengthen taxi delays when it was operating due to the need for the trainees to repeat taxi instructions and watch to see if indeed the aircraft began to move as instructed. By requiring unusually lengthy attention to individual aircraft it also was likely to have interfered with the scan measures.

An effort was made to quantify the effect of using the speech recognition system even though it was necessary to compare across trainee groups. Figure 3 shows the mean taxi delay for Group 1, during the first two weeks of automated system use (its use was discontinued during the third week, resulting in its use by some but not all trainees that week). The figure also shows taxi delay for the first two weeks of Group 2 and Group 3 training, combined for comparison to Group 1. The Week 1 scenario included 30 planes for Group 1, in contrast to 90 planes for Group 2 and Group 3, so the apparent advantage for the automated system is most likely an artifact. The Week 2 scenarios were more comparable: Group 1 was given 80 planes, nearly as many as the 90 planes given to Group 2 and Group 3. Using the Week 2 data, comparison of the first group while using the automated system with the second and third groups suggests that the automated system added an average of 1.77 minutes to the Group 1 taxi delay, roughly doubling this delay. Since the automated system appears to have adversely affected the Group 1 training data for the first two or three weeks, the Group 1 data was not analyzed further.

FIGURE 3. AUTOMATED SPEECH RECOGNITION/SYNTHETIC SPEECH: EFFECT ON TAXI DELAY



Due to the preceding considerations, the only training data analyzed came from the videotaped sessions of the second group of trainees. The four trainees in Group 2 each received simulation training for five weeks. One session per trainee per week was videotaped. Each session lasted approximately 50 minutes. Since the taxi delay, taxi time, and scan measures were all based on many individual observations, these data were considered to provide a sufficient basis for analysis.

A quantitative analysis of instructor comments on these 20 tapes supplemented the training data. This analysis was conducted to provide additional indications of the development of particular ground control skills and a better understanding of the simulation training process.

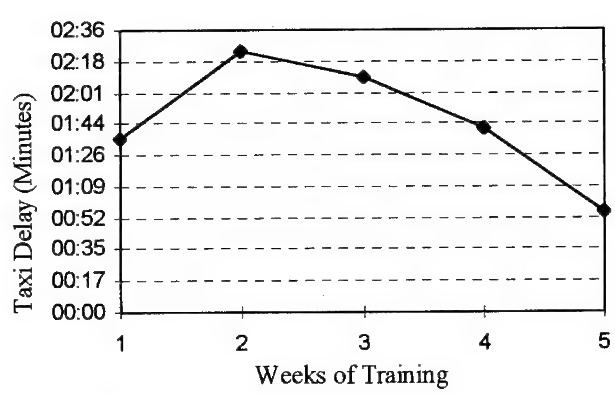
5.2.2 <u>Taxi Delay</u>

The time it takes the ground controller to provide taxi instructions to an aircraft that is ready to taxi is its taxi delay. At O'Hare, most aircraft receive taxi instructions in less than 30 seconds, which is considered a "good" taxi delay time at this facility[7]. Taxi delay provides a general indication of a controller's ability, including the ability to identify the gates and/or alleys used by air carriers at O'Hare, communicate efficiently, plan efficient taxi routes, and prioritize actions.

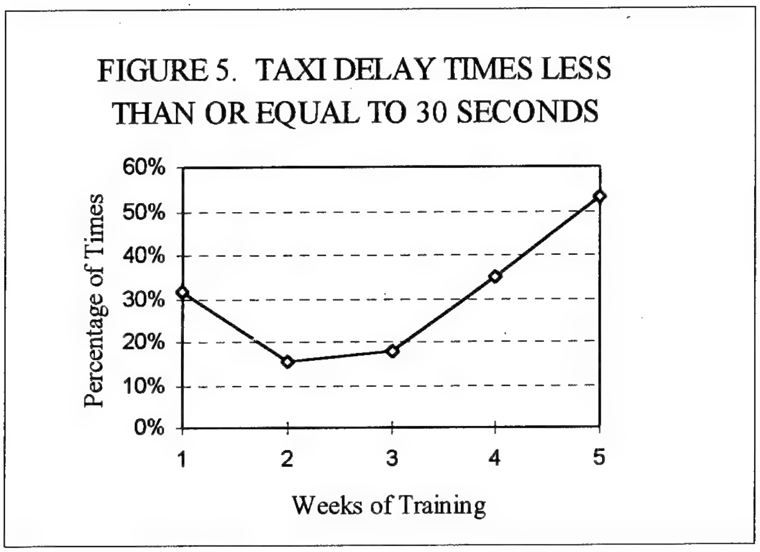
In the simulation, taxi delay was defined as the time interval that began when an aircraft was metered (i.e., when the ground meterer placed its flight strip on the strip bay) and ended when the aircraft received taxi instructions. It did not apply to an aircraft that was handed off by one ground controller to another ground controller (one aircraft in the videotaped scenarios).

Figure 4 shows the mean Group 2 taxi delay, by week of training. It demonstrates that following an initial rise, mean taxi delay decreased monotonically from a high during Week 2 of almost 2.5 minutes to a low during Week 5 of under one minute. This considerable decrease in mean taxi delay was accompanied by a corresponding increase in the percentage of taxi delays provided in at most 30 seconds (Figure 5).

FIGURE 4. AVERAGE TAXI DELAY




7. Matt Dunne. FAA O'Hare Tower. Personal Communication.




5.2.3 Taxi Time

Taxi time is a rough estimate of the time an aircraft spends taxiing and so it provides an indication of fuel cost to the user as well as an indication of how well a controller plans taxi routes. Taxi time varies with the distance from the departure gate to the point of handoff (usually near the departure runway), and hence with the type and company of the aircraft. Because it also varies with the distance to the appropriate, active departure runway, taxi time also varies with airport configuration. Following are typical taxi times for O'Hare[8] when the airport is either in its "Plan B" or its "Plan Weird" configuration (note that taxi time is reduced in the simulation due to the absence of inbound aircraft):

| | Departure Runway | Taxi Time (Minutes) |
|---|---|---|
| United | | |
| Eastbound | 22L | 8.5 |
| Westbound | 32L | 3 to 4 |
| American | | |
| Eastbound | 22L | 6 |
| Westbound | 32L | 8 |
| General Aviation | | |
| Eastbound | 22L | <1 |
| Westbound | 27L | 9 to 10 |

8. Matt Dunne. FAA O'Hare Tower. Personal Communication.

As measured in the simulation videotapes, an aircraft's taxi time began when it was given taxi instructions and ended when it was handed off to the local controller. The airport configuration or Plan was held constant (Plan Weird) in the Group 2 sessions videotaped.

Figure 6 shows the mean taxi times by week of training for Group 2. It is evident that taxi time remained relatively stable during the five weeks of training. The taxi times measured were considerably lower than most of those considered typical at O'Hare. It is likely that the times were low in part because no inbound aircraft were simulated. It is not clear why taxi time did not reflect the benefit of simulation training; however, it is possible that

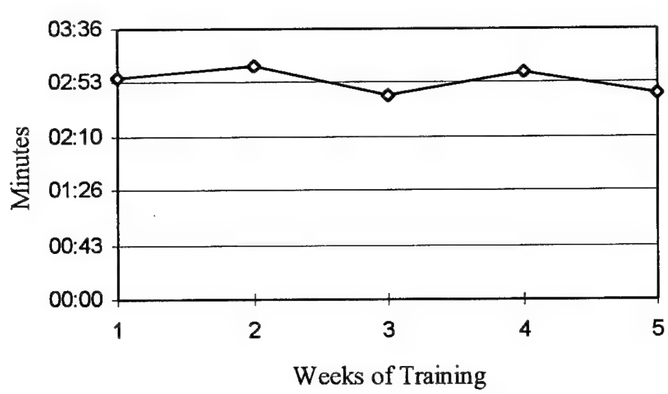
- taxi time depends mainly on the distance from the departure gate to the appropriate runway, with little effect of controller skill.

- the ground controller has more flexibility in how aircraft are handed off to the local controller, the event which closed taxi time in this study. Depending upon the situation, a handoff could occur in the same message as a taxi instruction, or it could wait until a later time when the trainee had an opportunity to make several handoffs in a single transmission. Time-to-runway (if measured) might show better sensitivity to training effects than time-to-handoff.

- the longer taxi time durations, compared to the length of taxi delays, made them more likely to include the time taken by instructors' assistance and comments.

- increases in skill were counteracted by increases in training program demands. Some of the later training demands such as traffic calls and splitting fixes could affect taxi time more than taxi delay.

FIGURE 6. AVERAGE TAXI TIME

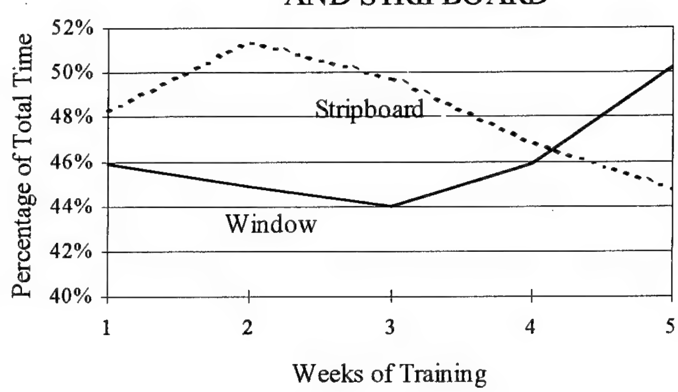


5.2.4 Window and Stripboard Scan

This pair of measures describes the length of time each trainee's visual scan or gaze was directed toward the simulation's visual displays (i.e., toward the simulated tower windows), the stripboard, or elsewhere in the training room (typically toward an instructor). Window scanning and stripboard scanning were of particular interest because of anecdotal reports that some trainees spend too much time looking at flight strips and consequently insufficient time looking through tower windows at the aircraft movement areas.

Stripboard management began to require less visual attention after the second week of training. It decreased between the second and fifth weeks from 51.4% to 44.8% of the total time. Window scanning began to increase after the third week from 44.0% to 50.2% of the total time. The direction of these moderate changes in gaze is consistent with the hypothesis that simulation training improves stripboard management skills. This evidence is presented in Figure 7.

FIGURE 7. SCAN TOWARD WINDOW AND STRIPBOARD




5.2.5 Analysis of Instructor Assistance

The constraints under which this study was conducted (see section 1.3) require a research strategy in which different types of evidence are examined for consistent trends. Accordingly, videotaped instances of instructor assistance were analyzed to provide converging evidence on the development of specific ground control skills.

Instructors made 782 discernible suggestions and comments during the 20 Group 2 training sessions that were videotaped and used in this evaluation. This instructor advice was examined to determine whether the trainees required less advice as training progressed. Each instructor comment was classified according to topic to provide additional indications of the development of particular ground control skills.

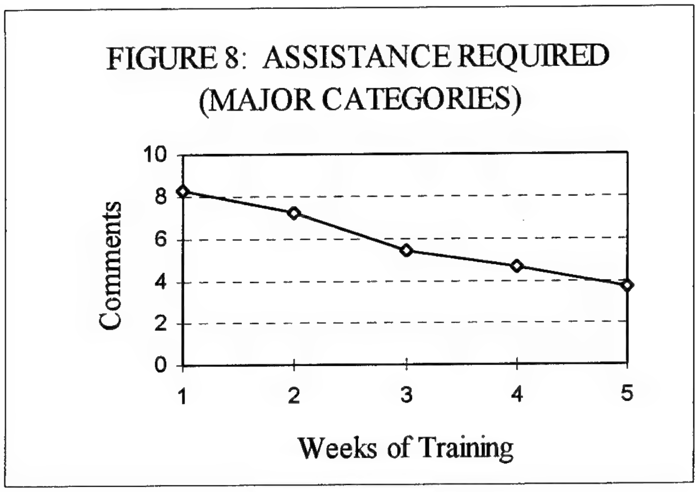
The instructor comments were classified into twelve categories. Six were designated as "major categories" and six were designated as "minor" on the basis of frequency. The major categories included 90.15% of the comments. For each week of training, the mean amount of advice (number of comments) in each of the major and minor categories is shown in Table 7. Figure 8 shows the effect of training on the average amount of assistance (per major category) trainees required to perform the problem. A trainee required roughly half as much assistance by the end of simulation training.

Table 7 shows reductions in advice on stripboard management and taxi routes, which appear to have reached asymptotes (minimum levels) by the end of simulation training. Priority of duty, (i.e., knowing which aircraft to call next) required instructor comments primarily during the first two sessions, after which comments appeared at a much reduced rate. Situational awareness is the only major topic that appears to have required a fairly constant level of instructor attention throughout training.

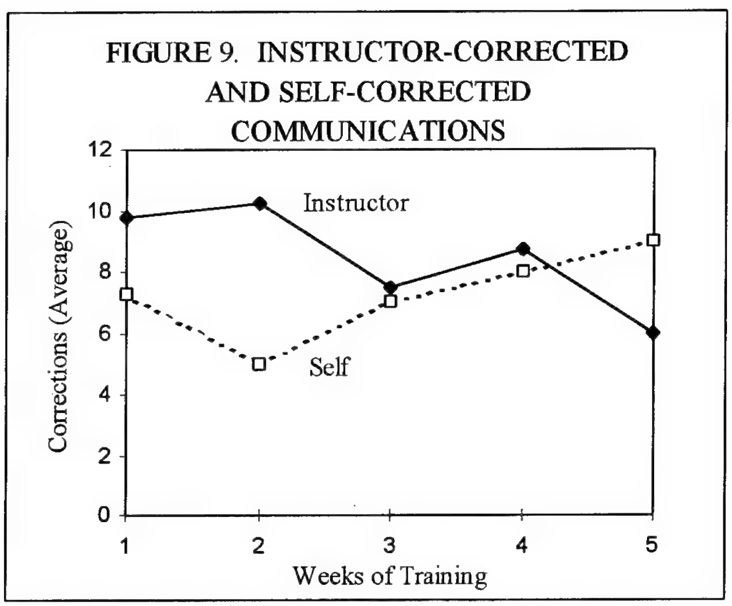
**TABLE 7. INSTRUCTOR ASSISTANCE BY WEEK OF TRAINING (MEAN NUMBER OF ASSISTS)**

| Categories Of Assistance | Weeks of Training | | | | |
|---|---|---|---|---|---|
| **Major Categories** | **1** | **2** | **3** | **4** | **5** |
| Stripboard Management | 10 | 6.25 | 4.5 | 3.5 | 3.25 |
| Situational Awareness | 5.25 | 5.25 | 6.75 | 4.5 | 4.75 |
| Priority of Duty | 10 | 9 | 3.25 | 3 | 2 |
| Communications | 9.75 | 10.25 | 7.5 | 8.75 | 6 |
| Taxi Routes | 9.75 | 9 | 7.25 | 5.5 | 5.5 |
| Traffic Calls | 4.75 | 3.5 | 3.5 | 2.75 | 1 |

| **Minor Categories** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Splitting Fixes | .5 | 3 | 1.75 | .75 | 1.75 |
| Timely Taxi Instructions | .5 | 1 | .25 | 1.25 | .75 |
| Handoffs to Local Controller | .75 | .25 | 0 | 0 | 0 |
| Aircraft Identification | .25 | .75 | .25 | 1 | .25 |
| Sequencing Aircraft | .75 | .25 | 1.25 | .5 | .5 |
| Runway Assignment | .5 | 0 | .25 | .5 | 0 |




As training progressed, instructors made fewer comments on the developmental controllers' communications. The highest number of comments were made during the first and second sessions. Compared to an average of approximately ten comments made in those initial sessions, the final session shows an approximate 40% reduction. Over the same period, the trainees increased the number of communication errors they caught and corrected themselves by more than 60%. Figure 9 presents these results.



## 6. FINDINGS AND RECOMMENDATIONS

This section summarizes and draws conclusions from the evidence presented in the preceding section. This evidence was gathered during the first year of training using a prototype out-of-the-window tower training simulator at O'Hare International Airport in Chicago. The simulator was used to train the skills and knowledge required to perform outbound ground control at O'Hare. The evidence supports the following conclusions:

**The out-of-the-window tower simulation used at O'Hare:**

- **is an effective tool for training many ground control skills and knowledge; it appears especially effective in increasing trainees' working speed.**
- **is more effective for training ground control than more traditional training techniques.**

### 6.1 TRAINING USING THE SIMULATOR WAS EFFECTIVE

During training, the ground control performance of the developmental controllers studied consistently improved, beginning with the second week of training. Following a month of simulation training, their ground control performance (in the actual tower) was rated as better than the performance of traditionally trained developmental controllers (see section 6.2). The following findings indicate improvements during the simulation training sessions, but do not permit comparisons between simulation and traditional training. The findings from comparisons between simulation and non-simulation training (listed in section 6.2) suggest that the improvements in ground control skills described in this section were due either to simulation training alone or to a combination of simulation and concurrent non-simulation training.

*Finding: Taxi delay decreased consistently from the second week to the end of training.*

The evaluation found a 50% decrease in average taxi delay duration, with a tripling of the percentage of taxi delays under 30 seconds in a comparison of the second and fifth (last) weeks of training. The monotonic downward trend was evident during each intervening week.

*Finding: Stripboard scanning began to consistently decrease after the second week of training, while window scanning began to increase after the third week of training.*

Moderate improvements in these two objective measures were found. Stripboard management began to require less visual attention after the second week of training, and ultimately decreased from 51.4% to 44.8% of the total scan time, a 7.7% decrease. Window scanning increased after the third session, from 44.0% to 50.2%, a 6.2% increase.

*Finding: The amount of assistance needed for a trainee to properly handle a scenario decreased consistently throughout training.*

The evaluation found a decrease of approximately 50% in the number of instructor assists from the first to the last week of training. The number of assists decreased in every major category of ground control skill. The major categories included Stripboard Management, Situational Awareness, Priority of Duty, Communications, Taxi Routes, and Traffic Calls. Stripboard Management and Priority of Duty showed the largest decreases.

## 6.2 TRAINING USING THE SIMULATOR WAS FASTER AND MORE EFFECTIVE THAN TRADITIONAL TRAINING

Developmental controllers became certified on the outbound ground control position in fewer days following a month of simulation training. Supervisors' ratings of their ground control skills indicated that they were further advanced, compared with the results of traditional training.

*Finding: The developmental controllers who were trained using simulation became certified on the outbound ground control position in fewer days, but required about the same total number of hours, as developmental controllers who were trained without simulation.*

Using facility records, comparisons were made on the number of days and the number of hours of OJT taken to become certified on the outbound ground control position. The evaluation found that it took the simulation-trained developmental controllers an average (mean) of 149 days to become certified on the outbound ground control position. In contrast, it took the developmental controllers who became certified on outbound ground control prior to simulation training 199 days, a statistically significant difference of approximately 25%. The two groups involved in these comparisons had received approximately the same amount of training prior to OJT.

The difference in days-to-certification found between developmental controllers trained using simulation and those trained without simulation did not appear to extend to total hours-to-certification. The evaluation found that simulation-trained developmental controllers took only 5% less time in terms of total hours-to-certification. This pair of results provides part of the evidence favoring a working speed hypothesis.

***The Working Speed Hypothesis:***

*Simulation training increased developmental controllers' working speed, which enabled them to work in the actual tower under a wider range of conditions (i.e., under heavier or more complex traffic) and hence for more hours per day than with traditional training. Thus, simulation training decreased the number of days but not the total number of hours needed for certification on position.*

Additional evidence in support of the working speed hypothesis is found in the supervisor ratings of eight skill categories, where working speed was rated highest compared to a baseline of traditional training. It received a mean rating of 3.71, which indicates that the trainee could work at a speed that is more than adequate for moderate workload (3.0) and close to adequate for high workload (4.0). Baseline ratings for controllers given traditional training were 1.3 for average learners and 2.7 for fast learners. The working speed hypothesis is also consistent with the finding of a 50% drop in taxi delay during the course of simulation training.

That simulation training did not appear to affect hours-to-certification suggests that simulation training did not address at least some critical ground control skills (see the following section 6.3). These skills apparently develop independent of working speed so that an increased working speed does not reduce the number of hours of OJT needed to develop these other skills.

*Finding: Supervisor ratings made after the completion of simulation training were higher than the ratings of traditionally trained developmental controllers.*

In general, the ratings made by tower supervisors indicated that within three weeks following simulation training, developmental controllers exhibited ground control skills in the actual tower comparable to a traditionally trained "average learner" after five months of OJT or to a "fast learner" after 2.7 months of OJT. The supervisors rated all eight categories of ground control skill higher following simulation training than following traditional training, even when compared to fast learners. Simulation training appeared most effective in increasing working speed.

## 6.3 TRAINING USING TOWER SIMULATION IS LIKELY TO SHOW INCREASED BENEFITS UPON UPGRADING

One difficulty of traditional OJT for outbound ground controllers is that, at times, the volume of traffic and its complexity can become so high that the trainee cannot proceed without potentially compromising the safe and efficient flow of aircraft to their runways. At these times, the trainee must leave his or her post and allow the instructor to take over. This reduces the amount of time for OJT on that day. The decreased taxi delays and higher supervisor ratings found in this study are consistent with the notion that simulation training increased the working speed of developmental controllers to the point where they could benefit from OJT even under conditions of moderate-to-high density and complexity.

The 25% difference in days-to-certification following simulation training was not accompanied by a commensurate reduction in hours-to-certification. These results suggest that some crucial ground control skills are not learned in simulation training as currently implemented. To the extent that these skills can be identified and simulation training enhanced, extended[9], or upgraded to support teaching them, one can expect additional benefits. Recommendations in this section are offered under the assumption that the FAA decides to proceed with tower controller training simulation.

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**9.** Many of the recommended simulation enhancements and new application areas (section 6.4) involve extending simulation training. This would increase training staff time and costs. The simulation's speech recognition and synthetic speech capability was intended to enable a trainee to practice without a simulation operator continually present. When the simulation speech system was operating, aircraft would automatically follow their assigned routes, and pilots would read back instructions and clearances automatically, using synthetic voice. Problems encountered in the use of the evaluated simulation's speech recognition and synthetic speech systems are described in section 2.2.3. If these problems are solved, autonomous capabilities could reduce the scheduling and financial costs associated with some of these enhancements and applications. Autonomous simulation capabilities could also increase the accuracy of assessments made in a simulated tower environment by increasing control over test conditions.

The evidence obtained in this evaluation suggests that upgrades are required to train or to increase the effectiveness of training on the following skills:

1. Inbound ground control and coordination between inbound and outbound ground control positions
2. Reflexive, correct communications
3. Scanning and situational awareness
4. Understanding what a pilot can see from the cockpit
5. Smooth transition between window scan and BRITE/ASDE displays
6. Teamwork

*Inbound ground control and coordination between inbound and outbound ground control positions.*
Without inbound aircraft, the simulation could not provide the complexity of the taxi patterns at O'Hare. This limitation reduced the maximum difficulty of the training problems, and it thus reduced the number of weeks the simulation could present challenging problems for training. **All of the upgraded capabilities listed below that involve extending the duration of simulation training require a capability for inbound aircraft.**

Ground control training conducted in a simulation lacking inbound aircraft could have led to the development of unrealistic expectations of the pace, decisions, and actions needed to move from one point to another because the outbound aircraft did not have to stop at the runways and taxiways used for arrivals. Also, without inbound aircraft, trainees did not have an opportunity to learn the coordination skills needed to work outbound ground control in tandem with an inbound ground controller.

Recommendations:

- Upgrade simulation technology to support inbound aircraft
- Upgrade simulation technology to include an additional position to be used for inbound ground control
- Extend the duration of simulation training.

*Reflexive, correct communications.* It appears that extended simulation training could improve trainee communication skills. As the emphasis during the month of simulation training changed from fundamental to advanced skills, so did the content of controller communications and their associated phraseology. This continual change in what was required of trainee communications could have produced the finding that more instructor assistance was provided in the communications category than in any other category during the last recorded training session. A related finding was that the total number of corrections in the communications category (self-corrections and instructor corrections) remained fairly constant throughout training. A trend toward less instructor assistance on communications after the second week of training suggests that trainees were learning better communication skills, but at end of simulation training, communications skills were among the least advanced, compared to traditional training, in supervisors' ratings. Together, these findings suggest that additional training could further promote the reflexive, correct communications that controllers require at airports like O'Hare, which are characterized by high aircraft density and complex traffic patterns.

Recommendation:

- Extend the duration of simulation training.

*Scanning and situational awareness.* Some results indicated that technical and/or procedural aspects of simulation training could be enhanced to increase the amount of time developmental controllers scan the airport. Objectively, scanning out the simulation windows increased 6.2% during the last two weeks of training. During this time, the amount of instructor assistance on situational awareness decreased, but it remained almost as high as at the start of simulation training. In supervisor ratings made soon after the completion of simulation training, scanning the airport was a skill rated less than average in strength, and less advanced compared to the other skills rated. These results suggest that scanning and situational awareness began to improve relatively late, and could benefit from additional simulation training. Possibly, the need to pan the displayed view of the airport may have slowed the integration of scanning into larger units of ground control skill, and may have limited the transfer of scanning skills from the simulation to the actual tower.

Recommendations

- Enhance the simulation to simultaneously display the entire airport.
- Extend the duration of simulation training.

*Understanding what a pilot can see from the cockpit.* Situational awareness for ground and local controllers includes an awareness of what pilots are likely to see at any given moment. This awareness is important when communicating instructions which commonly refer to aircraft relative to the pilot's position, as in "Join alfa behind the MD80 off your left." Situations arose during simulation training which suggested that ground controllers need training on what pilots are likely to see. For example, an instructor asked, "Which company do you think he's looking at?" On another occasion, an instructor commented on a trainee's instruction: "He may never see American off his left." A simulation capable of showing a realistic pilot's eye view could advance training on this aspect of situational awareness.

Recommendation

Provide a "pilot's eye view" capability that will realistically represent the view of a pilot from the cockpits of particular types of aircraft.

*Smooth transition between window scan and BRITE/ASDE displays.*

Developmental controllers could use current tower simulation to learn to translate aircraft locations as displayed on BRITE and ASDE systems from/to their locations as seen through the tower windows. Training in this advanced skill could lead to increased situational awareness.

Recommendations

- Upgrade the simulation technology to provide an interface to BRITE and ASDE displays showing aircraft coordinated to the simulation.
- Extend the duration of simulation training.

*Teamwork.* The simulation permits training for only one tower position. With enhancements, the simulation could be used to train developmental controllers to participate in the coordinated team effort required to control aircraft at O'Hare. Teaching teamwork and coordination skills requires the simulation to simultaneously show the entire airport. This capability would enable two or more controllers to view different parts of the airport at the same time.

Recommendations
- Upgrade simulation technology to support inbound aircraft.
- Upgrade simulation technology to include an additional position for inbound ground control or local control.
- Enhance the simulation to simultaneously display the entire airport.
- Extend the duration of simulation training.

## 6.4 CURRENT COST OF RECOMMENDED UPGRADING

The recommended upgrades are all currently available from the U.S. manufacturer of the prototype, Wesson International (Aviation Simulatons, Inc. is a joint venture of Wesson International, Inc. and the British Bruce Artwick Organization, Ltd.). Costs of the personal computer-based system depend primarily upon the number of controller or pseudo pilot/simulation operator stations, and on the number of projection screen displays. All current systems include simulated BRITE and ASDE displays and "pilot's eye view" capabilities. A system that includes all recommended upgrades (eight displays for a 360 degree view and three positions - two controller stations and a pseudo pilot/simulation operator station) would currently cost $1,050,950. A new system representative of the one evaluated at O'Hare (three displays for a 135 degree view, and one controller position, and a pseudo pilot/simulation operator station) would currently cost $495,950.

## 6.5 NEW APPLICATIONS OF TOWER SIMULATION TECHNOLOGY

Simulation training requires use of the simulator for roughly six months per year. Out-of-the-window ATC tower simulators offer additional potential uses which could be scheduled during the rest of the year, when the simulator is not required for training. The first topics concern advanced training for current full performance level (FPL) controllers. Sections follow on the use of tower simulation for candidate screening, and for the assessment of new tower training methods and technology and the evaluation of new automation systems, procedures, and airport configurations.

*Individual performance enhancement for current controllers.* The simulation evaluated does not appear able to provide sufficient volume and complexity to increase the skills of current FPL controllers at O'Hare or at other high density or high complexity airports. It would be essential to add a large volume of inbound aircraft to increase the difficulty of the training scenarios if training is to benefit current FPL controllers. This training could possibly enable them to provide better services and safety and to develop strategies for handling more traffic.

*Team performance enhancement for current controllers.* The current one-position simulation does not provide opportunities to train tower controllers to work more effectively together as a team. A multiple-position simulation with sufficient volumes of inbound and outbound aircraft would permit practice and training on situations requiring coordination and teamwork. The objectives of this training would be similar to those of crew resource management or CRM[10]. For example, they might include improvements in end-of-shift briefings, workload distribution, situational awareness, management of abnormal situations, and error surveillance.

*Training in the handling of unusual situations.* Using simulation, it would be possible to train tower controllers to recognize and properly handle situations rarely or infrequently seen in actual operations. Without operational experience, simulation would appear to offer the best way for controllers to learn to contend with the overall consequences of such situations for airport traffic control. Such situations include emergency landings requiring passenger evacuation, hijacked aircraft or other aviation security events, landings of diplomatic aircraft, aircraft taxiing on runways incapable of supporting their weight, fuel spills, birds or other wildlife on runways, unusual and dangerous airport weather (e.g., icy runways, windshear emergencies, or tornadoes), mechanical failures on aircraft, emergency medical flights, and aircraft with similar callsigns approaching a runway. Procedures for many of these situations appear amenable to simulation training and practice.

*The optimal conditions for training.* Out-of-the-window tower simulation technology offers the ability to control the training environment to a greater extent than the operational environment permits. The training staff at O'Hare took advantage of this new capability during the first year of simulation training by tailoring the volume of aircraft and the amount of guidance presented to the individual, and by modifying their training techniques between groups of trainees (see section 3.3).

This ability to control the training environment could lead to further efforts toward optimizing tower controller training. Training specialists could apply laboratory findings on the effects of experimental training conditions. For instance, in one study (Vidulich, Yeh, and Schneider, 1983[11]), a group of subjects that practiced a simulated air traffic control task that ran at twenty times real time performed better in some aspects (and the same in all other areas) than a group that practiced at real time. Algorithms for time-compressed information presentation have recently been developed[12]. The possibility of applying the lessons of such developments clearly depends upon the availability of adequate tower simulation facilities.

*Tower controller candidate screening.* Training resources are best allocated to the most highly qualified candidates. Current selection procedures consider only how a candidate appears on paper. The tower personnel who must select among candidates for a limited number of training

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**10**. Taggart, W.R (1994). Crew resource management: Achieving enhanced flight operations. In N. Johnson, N. McDonald, and R. Fuller (eds), Aviation Psychology in Practice, Aldershot, Hants, U.K., Averbury.

**11**. Vidulich, M., Yeh, Y., and Schneider, W. (1983). Time-compressed components for air-intercept control skills. Proceedings of the 27th Meeting of the Human Factors Society.

**12**. Guckenberger, D., Guckenberger, L. Luongo, F., Stanney, K., and Sepulveda, J. (April, 1995). Above-real-time training and the hyper-time algorithm. Dr. Dobb's Journal, 52-61.

slots have no direct knowledge of how well the candidates can perform under realistic task demands. They also lack clear evidence of motivational factors which can lead a candidate to expend special effort at preparation, such as studying the layout of the airport and surrounding airspace. In a realistic simulation, candidates can demonstrate their current knowledge and skills without affecting operations. Ideally, the tower staff would observe a candidate's demonstration of prerequisite knowledge and skills, and the ability to benefit from training in a simulation screening process which extends over several days. A draft document which describes the organization of a training candidate screening process using simulation is available from O'Hare Tower[13].

*Assessment of new tower equipment, procedures, and airport configurations: Cost-benefit studies.*

New tower automation systems, new procedures such as coded taxi routes, and new airport configurations (often involving new or extended runways) promise to increase airport capacity and to improve airport safety and the services provided by tower controllers. Assessment is needed to determine the extent to which the goals of each new system, procedure or configuration are reached, to determine its effect on the overall tower environment, and to assess proposed design modifications. Although the assessment of each new system can include unique considerations, controllers' visual, manual, pilot communications and coordination workload, and their response times, errors, decision making, and situational awareness are common considerations. Such assessments must first be made in the context of the current tower environment to provide a baseline for comparison with the new automation system, airport configuration, or procedure.

Some pertinent measures cannot be made in an operational environment because they could interfere with tower operations or because the necessary control over the situation is lacking. Examples include testing controller response time to identify the cause of alarms and respond appropriately, to identify and correct a controller error, or to identify and correct pilot deviations from controller instructions. In these cases, the initiating events occur too rarely in actual operations and would have to be simulated. It would also appear impractical to test the actual consequences of automated taxi route decisions, or to determine whether controllers can safely monitor them. The measurement of situational awareness technically requires stopping the situation to collect data[14]. Other measures, such as the frequency of manual activity and data input errors, are best measured automatically through direct connections to the device, connections which would require fabrication. In general, the most accurate and relevant measurements can be made in an operational situation, in the presence of realistic workload, distractions, time demands, and stress. However, as these examples suggest, the operational situation may not be suitable to the required measures, requiring instead the use of global or subjective measures which could lead to less accurate conclusions.

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**13**. FAA/Great Lakes Region/O'Hare Tower. (Undated Draft). O'Hare Air Traffic Control Tower Performance Verification Program. Author.

**14**. Endsley, M. (1995). Measurement of situational awareness in dynamic systems. Human Factors, 37(1), 65-84.

Out-of-the-window tower simulation could provide a more convenient and practical testbed for the assessment of new tower automation systems than operating towers. It would appear particularly useful in the assessment of automation systems to be used by local and ground controllers, whose work depends upon viewing aircraft movement areas. A list of recommended requirements for an assessment simulator is presented in Appendix C.

## APPENDIX A: FOCUS GROUP SUMMARY

This focus group was conducted with four developmental controllers in the first group after they had 7 to 10 hours working at the outbound ground control position, following 20 hours (4 weeks) of simulation training. Following is an edited summary of the session.

*In what ways is actual ground control different from the simulation?*
- Because of the need to scroll the simulation it is harder to keep track of AC in peripheral vision and to know when to transfer the AC.
- Simulation workload is constant because it presents planes at a regular pace, unlike the real tower where the workload occurs in "clumps". There is no "breathing time" in the simulation.
- The simulation's graphic resolution is sometimes "grainy" and its colors less intense, adding a half second to the time it takes to identify aircraft. For example, one must reason from type (737) to company (not American, therefore United) to check yourself; upstairs you would know instantly.
- More small planes, Eagles and Gulfs, in actual traffic than in simulated. Maybe needs updating.

*In what ways was the simulation an effective teaching tool?*
- Learning taxi routes.
- It eliminates worry about real aircraft moving around and the training specialist stepping in to fix something instantly or to make something work. It provides a less pressured, more relaxed environment instead of needing to fix it instantly.
- It permits control over the pace of the problem. Upstairs when its slow its too slow; when busy it is too busy; there seems to be no happy medium.

*Was the pace of the simulation optimally challenging throughout all four weeks?*
- It began a little too slow at 1 plane per minute, and too fast at the end (1 per 30 sec) when learning to make splits. The speed jumped up sometimes before I caught on.

*If there was another month of simulation what would you like to cover?*
- Splits, and more varied scenarios, including surges and rest, different planes and different rushes, instead of always starting up west and ending up with west.
-Rehearsal of actual rushes and regularly scheduled flights in all configurations.

*Any advice for the next group of developmentals to receive simulation training?*
- Focus on managing stripboard.
- Don't worry about making mistakes or looking stupid, and ask questions instead of pretending to understand.

*How might the simulation be used better?*
- Instructors should use the pause feature more to allow evaluation of what has just occurred, in smaller chunks, identifying problem and solution.
- Speed up the problems at the beginning to make them more realistic.
- Reduce the speed of a problem when first increasing its complexity.
- Use 1 or 2 instructors full time instead of many instructors because they teach different techniques for doing the same thing.

*According to the trainees, the following topics are learned better with live traffic than through simulation training (although with "additional tweaking" the simulation could help with these):*
- Split fixes.
- Relative taxi speeds.
- Location: It is easier to see planes waiting for departure on the approach end of a taxiway in the real tower, than on the simulator. - Visual scan: One learns to move around in the actual tower, whereas one always looks straight ahead in the simulation. One does learn where to scan in the simulation.
- Aircraft identification: The simulation picture is not sharp enough to identify companies.

*Did the simulation help you learn...*
*Efficient traffic flow?*
- Yes. It provides practice on maintaining continuous attention and not wasting time

*Making traffic calls?*
- No. [sorry, I did not ask for elaboration]

*Increased working speed?*
- Yes.

*Coordination with inbound ground controller?*
- No, because there was no inbound traffic to coordinate.

*Flight strip marking and stripboard management?*
- It provided good help, although more work is needed to get the instructor, student, and simulation working at the same speed.

*Phraseology and correct frequencies?*
- It was helpful for learning to use correct frequencies. The voice recognition was too picky, failing to accept an instruction if the student said "the" instead of "a", spoke too loud, soft, or fast. It distracted from what the student was trying to learn.

*Dealing with similar callsigns?*
- It never came up.

*Avoiding unnecessary verbiage?*
- The training helped, but not the simulation's voice recognition.

*Any other aspects of your present work with actual traffic where you are finding that the simulation helped?*
- The location of gates and where to look for airplanes calling to taxi out. It sped up the learning process.
- "I can't really put it in numbers, but I feel a lot better about approaching the ground control learning after a month here.... I feel well ahead of the game here."
- "I think it was very beneficial...I think it helped in all areas...it greatly helped with stripboard management, stripmarking, and phraeology, not from voice recognition, but from practice and repetition, saying the routes over and over.

*How did the speed of the simulation compare with actual traffic?*

- The speed of the simulation problems was in same range over slow periods, but it did not get as fast as it does upstairs; the 7:30 rush does not compare to the simulation.
- It is hard to compare without inbounds in the simulation because inbounds can become confused with your [outbound] traffic (which adds complexity). "You are looking at more than your guys upstairs; you are looking at everything."

*What improvements would be most important?*

- A 360 degree screen would help the most.
- Simulation operators to run remote positions; one to run inbounds, another to be the pilot for the outbounds, and then there would be the instructor, watching. You could set up traps where certain pilots miss their instructions.
- Voice recognition would be valuable if it allowed a student to practice without imposing on others' time. This would allow for the additional practice needed to develop habits which in turn would translate to time saved. Four weeks were not enough to develop stripmarking and stripboard management skill habits; "I didn't get to writing the number on the strip, looking out the window and moving it, all without thinking. I still had to think about writing the number on the strip, moving the strip, and sequencing it, and figure out which one's an American and which one's a United and putting them between those two. The habits didn't come for me as fast as they said they should because if you do it only one hour per day for 20 days...."

## APPENDIX B: BASELINE DEVELOPMENT OF GROUND CONTROL SKILLS

**"Average Learner"**

| Ground Control Skill | 1 wk | 1 mo | 2 mo | 4 mo | 6 mo | 8 mo | 10 mo | 12 mo |
|---|---|---|---|---|---|---|---|---|
| Visually scans airport surface | 2.0 | 2.0 | 2.7 | 3.0 | 4.0 | 5.0 | 5.0 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Maintains efficient traffic flow | 1.3 | 2.0 | 2.0 | 2.7 | 3.7 | 4.3 | 4.7 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Maintains aircraft identity | 1.7 | 2.0 | 3.0 | 3.0 | 4.0 | 4.7 | 4.7 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Effectively manages stripboard | 1.3 | 1.7 | 2.3 | 2.7 | 3.7 | 4.0 | 4.7 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Working speed | 1.3 | 1.3 | 1.7 | 2.7 | 3.3 | 4.3 | 4.7 | 5.0 |
| 1=Very Slow 2=Adequate for Low Workload 3=Adequate for Moderate Workload 4=Adequate for High Workload 5=Adequate for Very High Workload | | | | | | | | |
| Missed/delayed traffic calls | 1.0 | 1.0 | 1.3 | 2.7 | 3.3 | 4.3 | 4.3 | 4.7 |
| 1=Many 2=Some 3=Few 4=Almost None 5=None | | | | | | | | |
| Communication is clear & concise | 1.7 | 1.7 | 2.3 | 3.3 | 4.0 | 4.7 | 4.7 | 4.7 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Makes unnecessary transmissions | 1.0 | 1.0 | 1.7 | 2.3 | 3.7 | 4.0 | 4.3 | 4.7 |
| 1=Many 2=Some 3=Few 4=Almost None 5=None | | | | | | | | |

**"Fast Learner"**

| Ground Control Skill | 1 wk | 1 mo | 2 mo | 4 mo | 6 mo | 8 mo | 10 mo | 12 mo |
|---|---|---|---|---|---|---|---|---|
| Visually scans airport surface | 2.0 | 2.7 | 3.7 | 4.0 | 4.7 | 5.0 | 5.0 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Maintains efficient traffic flow | 1.3 | 1.7 | 2.7 | 3.3 | 4.3 | 5.0 | 5.0 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Maintains aircraft identity | 2.3 | 2.7 | 3.7 | 4.0 | 4.7 | 5.0 | 5.0 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Effectively manages stripboard | 2.0 | 2.0 | 3.0 | 3.7 | 4.7 | 5.0 | 5.0 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Working speed | 2.0 | 2.7 | 2.7 | 3.7 | 4.0 | 4.7 | 5.0 | 5.0 |
| 1=Very Slow 2=Adequate for Low Workload 3=Adequate for Moderate Workload 4=Adequate for High Workload 5=Adequate for Very High Workload | | | | | | | | |
| Missed/delayed traffic calls | 1.3 | 1.7 | 2.7 | 3.3 | 4.0 | 4.3 | 4.7 | 4.7 |
| 1=Many 2=Some 3=Few 4=Almost None 5=None | | | | | | | | |
| Communication is clear & concise | 2.3 | 3.0 | 3.3 | 4.7 | 4.7 | 4.7 | 4.7 | 5.0 |
| 1=Never 2=Seldom 3=Often 4=Almost Always 5=Always | | | | | | | | |
| Makes unnecessary transmissions | 2.0 | 2.0 | 2.7 | 3.7 | 4.3 | 4.7 | 4.7 | 5.0 |
| 1=Many 2=Some 3=Few 4=Almost None 5=None | | | | | | | | |

## APPENDIX C: OUTLINE OF RECOMMENDED REQUIREMENTS FOR A TOWER SYSTEM ASSESSMENT SIMULATOR

A. Display

1. Room space sufficient to replicate largest tower
2. Moveable realistic-size window displays each showing the view from one side of the actual tower
3. All tower window views displayed simultaneously
4. Photographic color images of entire airports, readily updatable
5. Color photographic images of aircraft of types and companies appropriate to airport, readily updatable
6. Inbound and outbound aircraft in local controller airspace at realistic speeds which vary with aircraft type
7. Aircraft taxiing in and out at realistic speeds which vary with aircraft type
8. Capable of exchanging the photograph of one airport for another airport
9. Maximum volume of aircraft equal to future enplanements predicted for simulated airport
10. Aircraft and gates individually scheduled
11. Ability to remove, modify, and rename current taxiways and runways and to create new or extended taxiways and runways
12. Sessions recorded for playback

B. Control (by human operator or automated system)

1. Individual aircraft movements along specified taxiways and runways
2. Takeoff/landing roll and liftoff/landing at realistic runway positions and speeds
3. Verbal responses transmitted through controller headsets

C. Positions (include furniture and devices)

1. ATC (8): two ground control, two local control, flow manager, flight data, clearance delivery, supervisor, and
2. Simulation operator/pilot positions (4): two respond to local control; two respond to ground control, or
3. Automated speech recognition/synthetic pilot and one simulation operator who can override the automated pilot systems

D. Interface to systems under test

1. Actual current and new system user interface
2. Capable of simulating inputs to current or new systems
3. Capable of simulating faults in new systems
4. Adaptable to new automation system interfaces
5. Quickly reconfigurable with different combinations of equipment

E. Interface to controller performance data logging equipment

1. Source of input (device used)
2. Identity of data or command correctly or incorrectly entered
3. Time-logging of all data collected, synchronized to simulation

F. Additional data collection

1. Videotape from each window display location, synchronized to simulation
2. Audiotape from each control position, synchronized to simulation
3. Record of simulation operator commands and time entered